Transportation and Stationary Power Integration with Hydrogen and Fuel Cell Technology in Connecticut

Connecticut Center for Advanced Technology, Inc.

CCAT Energy Initiatives: Joel M. Rinebold

Strengths, Weaknesses, Barriers

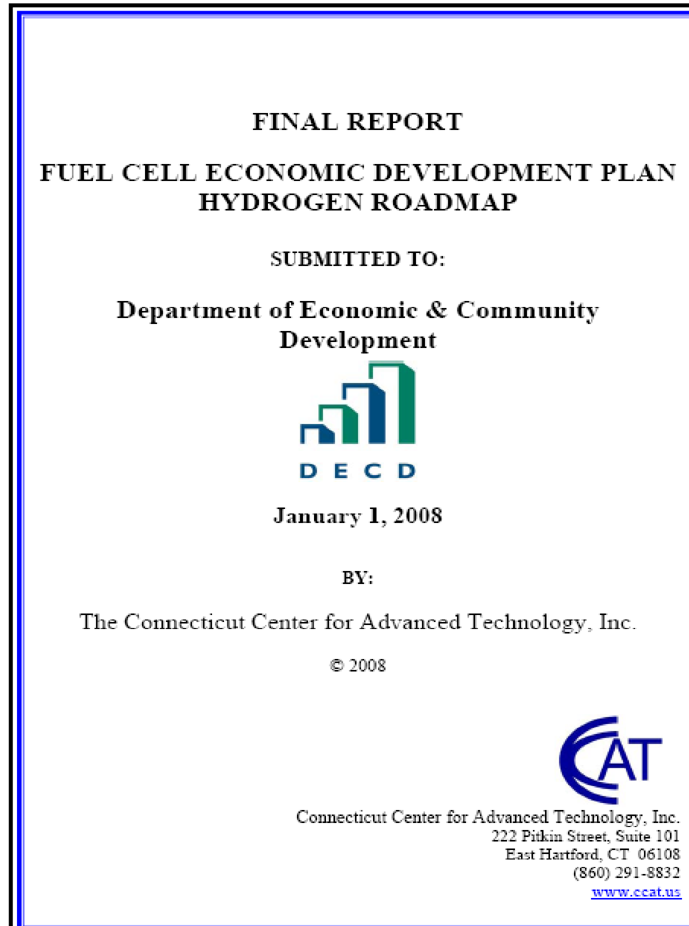
- Strengths
  - Value for Energy
  - Value for Environment
  - Value for Economy
- Weaknesses
  - Lack of Planning and Analysis
  - Lack of Value Internalization
- Barriers
  - Market Acceptance for D.G.
  - High Cost Due to Low Production
  - Predictable Investment

Hydrogen Roadmap

Implementation Strategy:

- Market Analysis
- SWOT Analysis
- Market Targeting
- ROI Analysis
- Technical Analysis
- Economic Analysis
- Environmental Analysis
- Policy Analysis
- Communication Plan
- Implementation Plan

CT Hydrogen Roadmap



FINAL REPORT

FUEL CELL ECONOMIC DEVELOPMENT PLAN
HYDROGEN ROADMAP

SUBMITTED TO:

Department of Economic & Community Development

DECD

January 1, 2008

BY:

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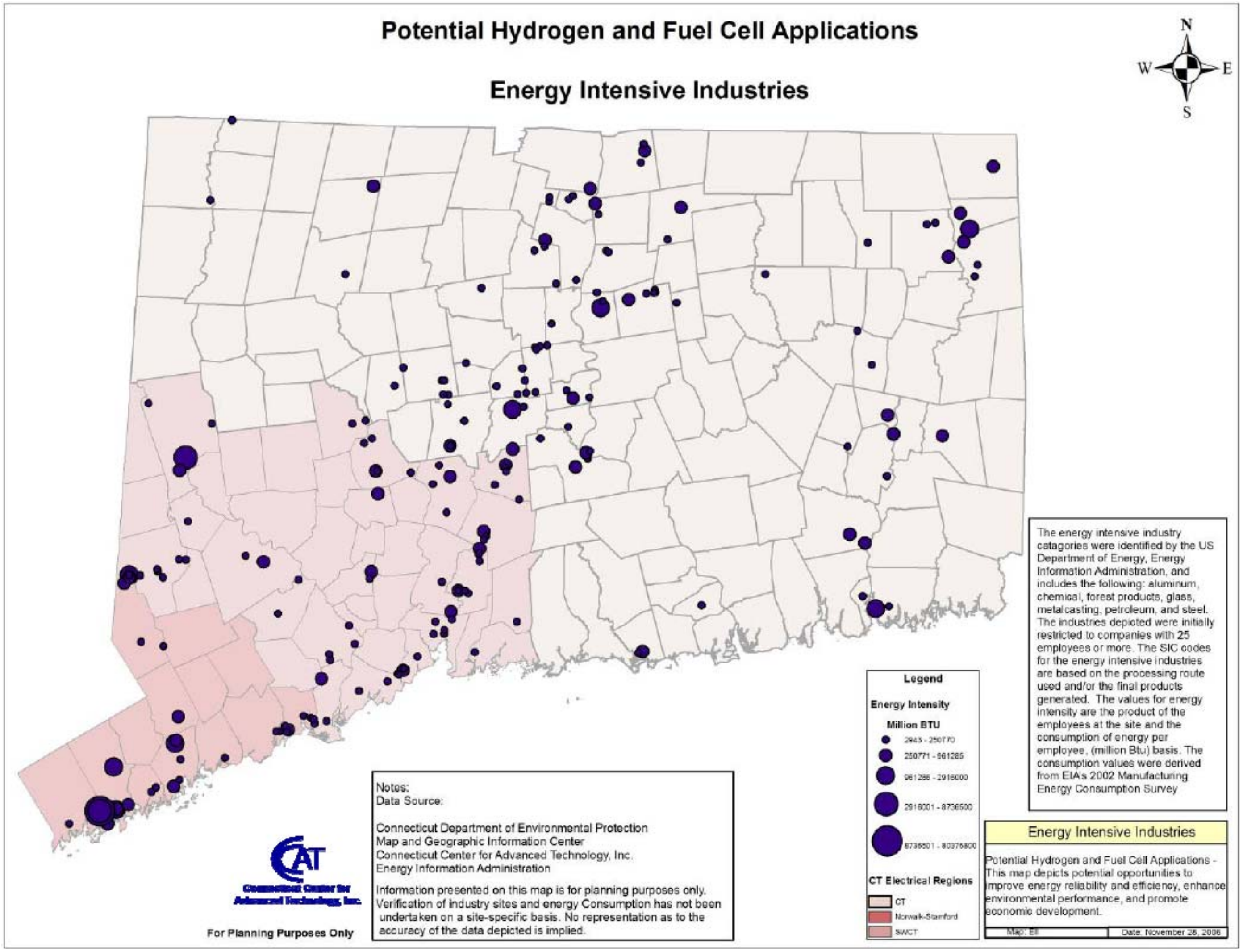
Factors: Emphasis on Long-Term Market Drivers

- World electric consumption to double between 2003 and 2030.
- Transportation demands for petroleum exceed domestic supply.
- Increased energy efficiency required (oil cost/bbl).
- Reduced emissions of greenhouse gases and primary air pollutants.
- Growth of peak electric demand and need for D.G.
- New generation capacity to meet additional demands.

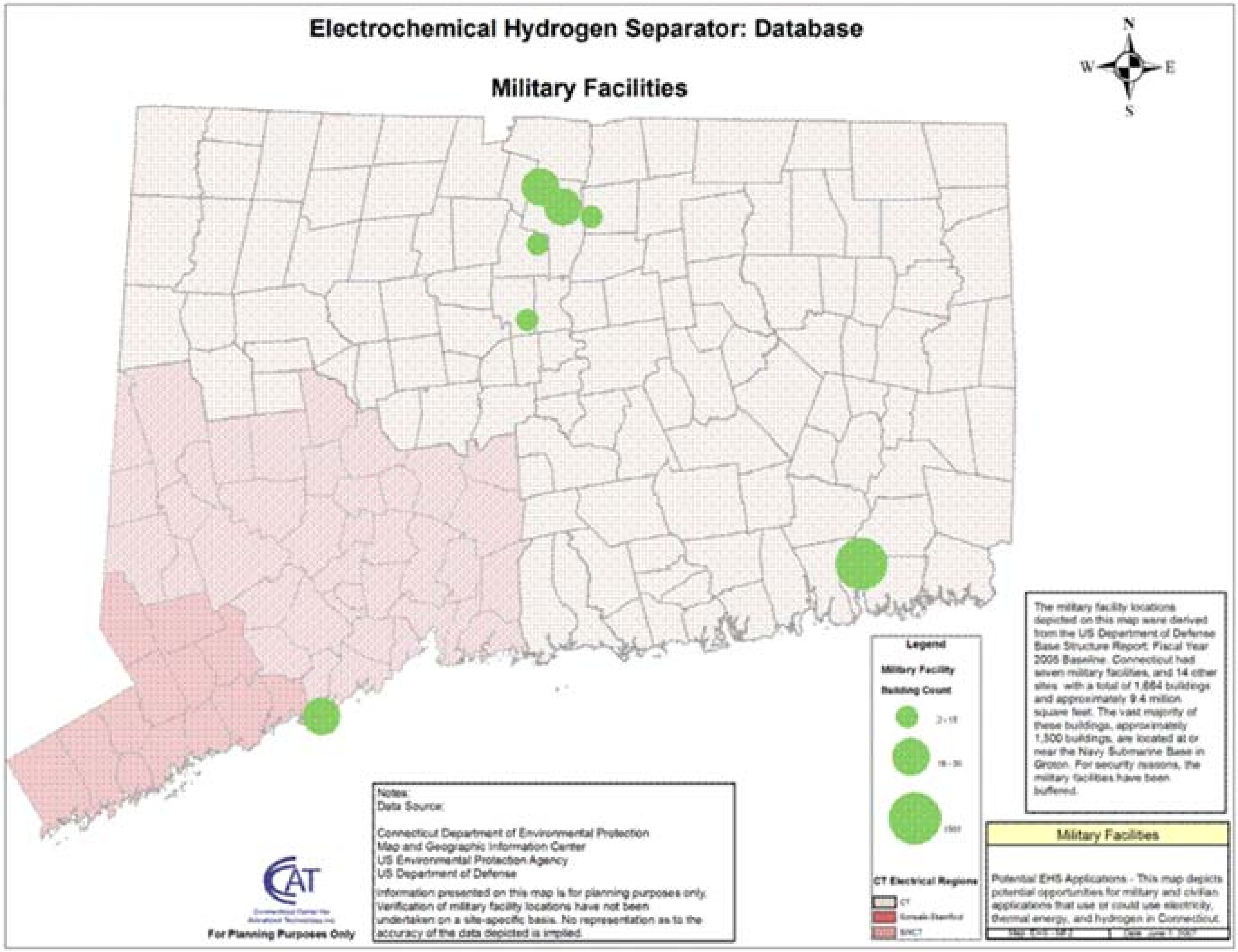
Section Criteria: Analytical Approach Required

- Identification of Local and State Resources
- Integrate with Municipal Infrastructure
- Geographic Energy Targeting
- Technical Balancing with Heat and Power (and Hydrogen)
- Financial Analysis
- Environmental Analysis

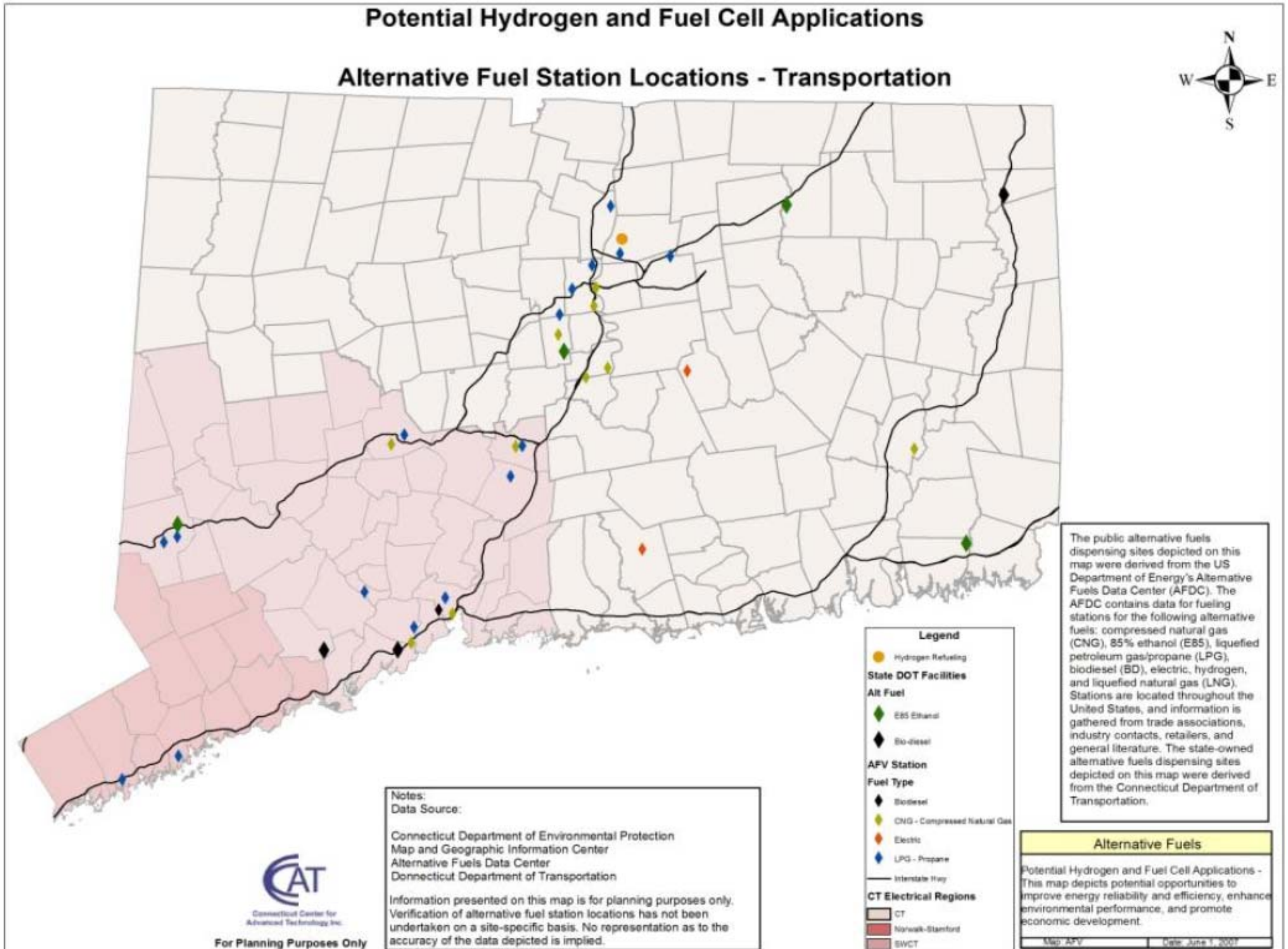
Energy Intensive Industries



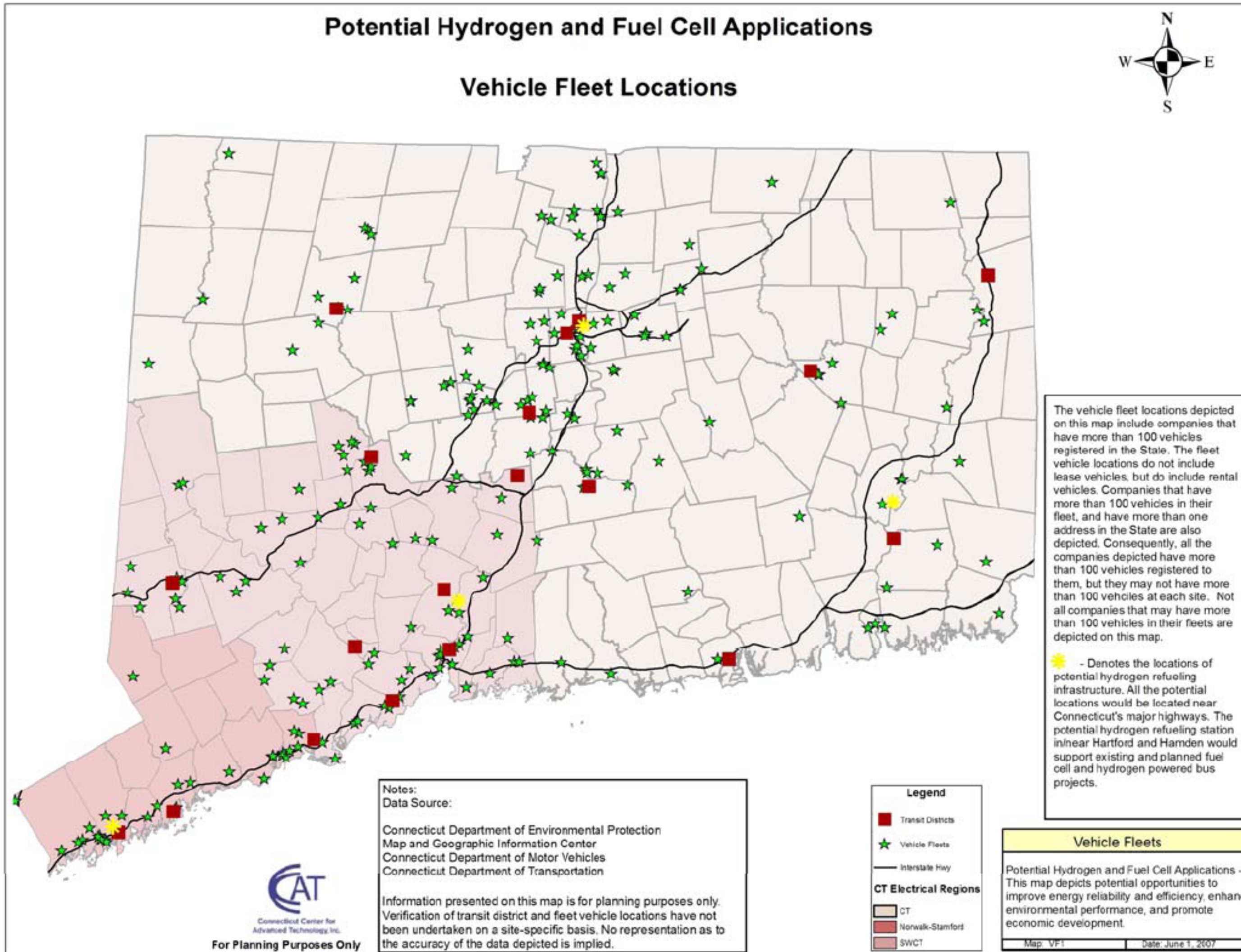
Military Facilities



Alternative Fuel Station Locations



Vehicle Fleet Locations



Transportation Infrastructure Deployment

- Elements:
  – Phased Approach Timed with Market Drivers and an Investment Plan
  – Routes Identified by Fleet and Transit Locations
  – Siting Determined by Maximum Internalization of Value Including CHP
  – Participants Identified by Market Drivers

Phase I Transportation Infrastructure Deployment

– Establish a Hartford area fueling station
  - Urban to urban commuter route
  - Transit infrastructure is currently in place

– Develop partnerships and educate policymakers on project goals

– Identify hydrogen vehicles for project
  - Hartford fuel cell bus in place

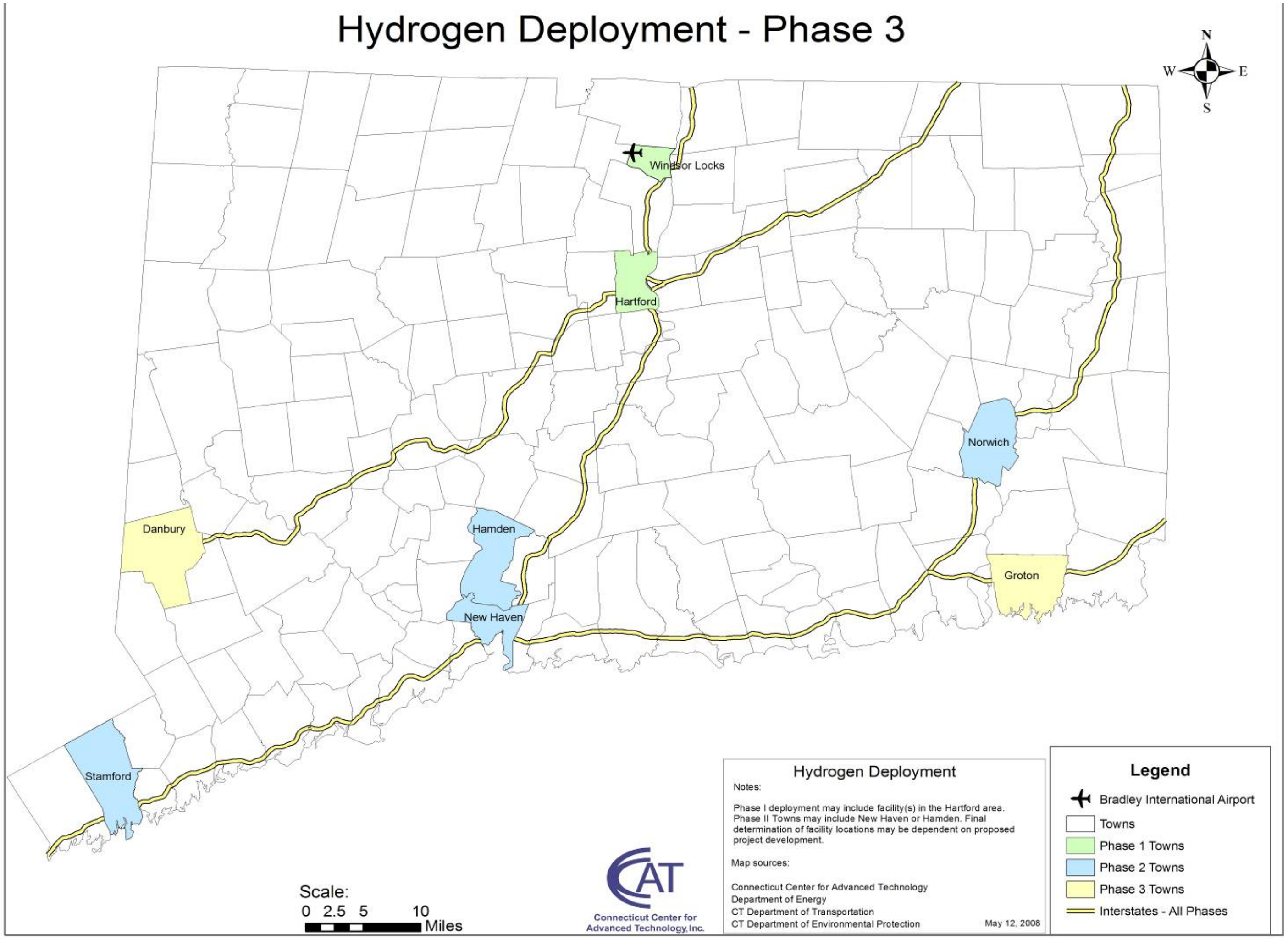
Phase II Transportation Infrastructure Deployment

- Establish multiple transit routes for "Hydrogen Highway Project"
  - Suburban to urban commuter routes
  - Urban to urban commuter routes
  - Transit routes
- Utilize advanced technology for project
- Expand infrastructure to support vehicles for fleet operations and public transportation at multiple locations
  - Refueling stations in Stamford, New Haven, and Norwich

Phase III Transportation Infrastructure Deployment

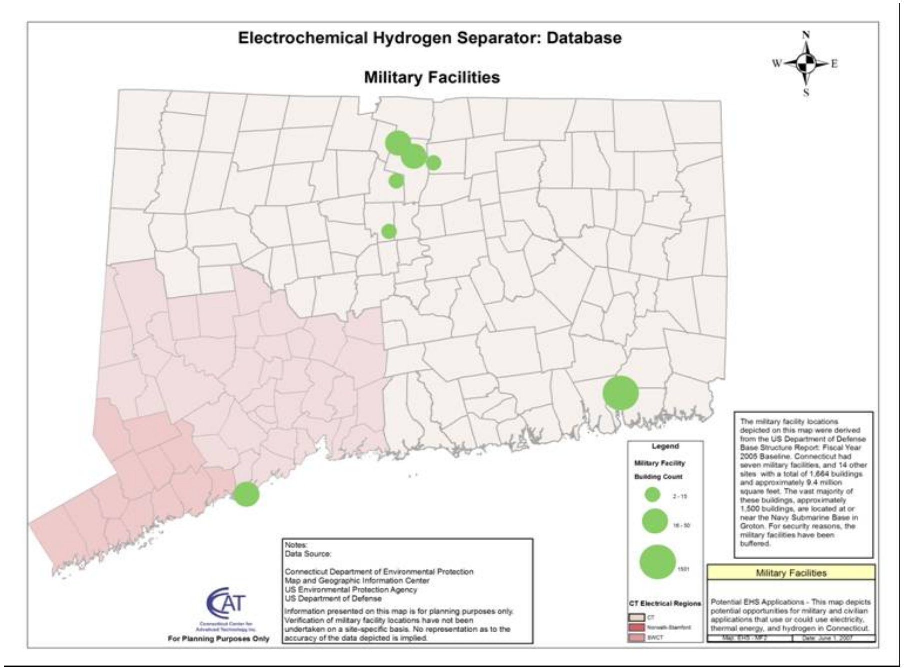
- Establish multiple transit routes for "Hydrogen Highway Project"
  - Suburban to urban commuter routes
  - Urban to urban commuter routes
  - Transit routes
  - Transportation Hub
- Utilize advanced technology for project
- Expand infrastructure to support alternative-fueled vehicles for fleet operations, public transportation, and private use at multiple locations
  - Refueling stations in Groton and Danbury

Phase III Transportation Infrastructure Deployment



Site Selection Criteria

- Transportation Opportunities
- Electricity Demand
- Thermal Use
- Hydrogen Demand
- Energy Reliability
- Economic Development
- Energy Availability
- Environmental Opportunity
- Community Support
- Educational Value/Community Support
- Military Application



Military Sites Screened in CT*

Site	Buildings	SQFT	Estimated kW Need	Acres	Component	Place
Bradley ANG	33	319,255	277	148	Air National Guard	Windsor Locks
Orange ANG Communication Station	4	60,673	53	29	Air National Guard	New Haven
AASF	14	152,270	132	32	Army Guard	Windsor Locks
AVCRAD Groton	15	193,050	167	24	Army Guard	Groton
Camp Hartell	43	142,251	123	59	Army Guard	Windsor Locks
Camp Rell	65	323,837	281	82	Army Guard	Niantic
Hartford Armory OMS 8A	5	306,546	266	6	Army Guard	Hartford
New Britain Armory	1	26,995	23	8	Army Guard	New Britian
New London Armory	1	38,175	33	8	Army Guard	New London
Newtown Military Reservation	3	54,191	47	95	Army Guard	Newtown
Norwalk Armory	2	31,966	28	11	Army Guard	Norwalk
Norwich Armory OMS 10	4	50,073	43	11	Army Guard	Norwich
Southington Armory OMS 2	4	32,245	28	10	Army Guard	Southington
Stones Ranch Military Reservation	22	78,120	68	1862	Army Guard	East Lyme
Stratford Armory OMS 9	2	46,114	40	10	Army Guard	Stratford
Berry-Rosenblatt AFRC	2	163,763	142	12	Army Active	West Hartford
BG John W Middleton USARC	5	66,120	57	16	Army Active	East Windsor Hill
Stratford Army Engine Plant	42	1,618,526	1404	124	Army Active	Stratford
Bloomfield	6	93,031	81	85	Navy Active	Bloomfield
Conning Towers	83	246,215	214	50	Navy Active	Groton
Dolphin Gardens	1	47,779	41	40	Navy Active	Groton
Nautilus Park 1st Inc	501	678,581	589	50	Navy Active	Groton
Nautilus Park 2nd Inc	263	647,714	562	142	Navy Active	Groton
Nautilus Park 3rd Inc	4	35,992	31	115	Navy Active	Groton
New London	274	2,905,338	2521	687	Navy Active	Groton
Polaris Park	91	399,255	346	52	Navy Active	Groton
Trident Park	155	605,914	526	86	Navy Active	Groton

*Site screening of 27 sites completed.

Military Sites Analyzed* in CT

Military sites around the Bradley International Airport Area:

- **Camp Hartell** - Windsor Locks
- **Connecticut Air National Guard** - East Granby
- **Army Aviation Support Facility (AASF)** - Windsor Locks

- **Hartford Armory** (Hartford)
- **Aviation Classification and Repair Depot** (AVCRAD) - Groton
- **Naval Submarine Base** – New London
- **Air National Guard Communication Station** - Orange

* - Preliminary Assessment Completed for Seven Sites

Military Sites Analyzed* in CT

Camp Hartell

- 43 buildings located in Windsor Locks
  - 142,251 SQFT
- 59 acres owned
- Off-base housing for soldiers (Residential)
- Warehouses supplies
- Combined Support Maintenance Shop (CSMS) $32,000,000 - FY2012
- Estimated 225 kW** electrical requirement (7.6 kWh/SQFT)
- Estimated 700,000 BTU/hr** thermal requirement (23.4 cubic feet natural gas/SQFT)

*- Preliminary Assessment Completed for seven sites
**- Includes Planned Expansion

Military Sites Analyzed* in CT

Army Aviation Support Facility (AASF)- Army Guard

- Two hangars + associated support buildings
  - 14 buildings owned in Windsor Locks
    - 152,270 SQFT
- 32 Total Acres (22 acres of Bradley International Airport)
- 5 Chinook heavy helicopters
- 5 UH-60 Blackhawk utility helicopters
- 1 C012U turbo prop airplane
- 210 soldiers trained by AASF

- Aviation Transformation Readiness Center (ATRC) $46,000,000 in FY2011
- Estimated 250 kW** electrical requirement (7.6 kWh/SQFT)
- Estimated 750,000 BTU/hr** thermal requirement (23.4 cubic feet natural gas/SQFT)

*- Preliminary Assessment Completed

**- Includes Planned Expansion

Military Sites Analyzed* in CT

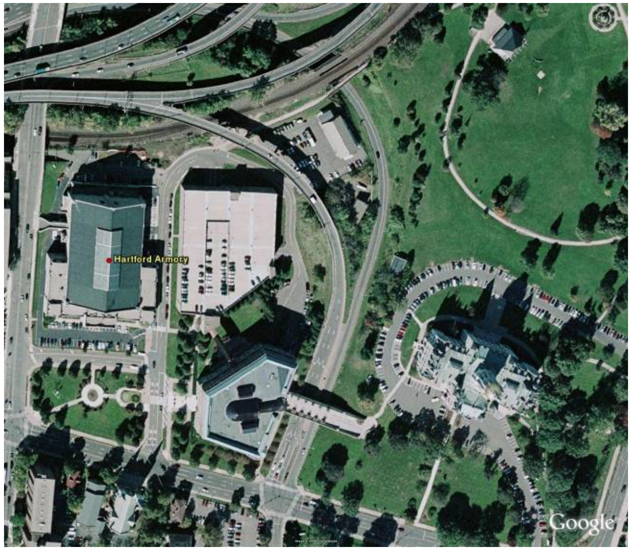
Connecticut Air National Guard

- 33 buildings owned in Windsor Locks/East Granby
  - 319,255 SQFT
- 148 acres
- 817 Airmen
  - 282 full-time/535 part-time
  - In 2006, 125 deployed across world
- 14 A-10s
- 8 C-21s for VIP/Medical Airlift
- C-27 Joint Cargo Aircraft (JCA) in 2012

- Consolidated Immediate Repair Facility (CIRF) for TF 34 jet engine
- Air Operations Center (AOC)
- Estimated 250 kW electrical requirement (7.6 kWh/SQFT)
- Estimated 875,000 BTU/hr thermal requirement (23.4 cubic feet natural gas/SQFT)

* - Preliminary Assessment Completed

Military Sites Analyzed* in CT



Hartford Armory

- 5 buildings in Hartford
  - 306,546 SQ FT
- 6 Acres
- Serves as a communications hub in the event of an emergency
  - Provides military base power
  - Aids Connecticut's civil preparedness and military operations.
- Estimated 266 kW electrical requirement
- Estimated 844,240 BTU/hr thermal requirement (23.4 cubic feet natural gas/SQ FT)

* - Preliminary Assessment Completed

Military Sites Analyzed* in CT

Aviation Classification and Repair Depot (AVCRAD)

- 15 buildings located in Groton
  - 193,050 SQFT
- 24 acres
- 272 soldiers assigned or attached to unit
- Operates the Theater Aviation Maintenance Program (TAMP)
- Focus on the replacement of stay-behind-equipment (SBE) for improvements
- Estimated 150 kW electrical requirement (7.6 kWh/SQFT)
- Estimated 525,000 BTU/hr thermal requirement (23.4 cubic feet natural gas/SQFT)

* - Preliminary Assessment in Progress

Military Sites Analyzed* in CT

Naval Submarine Base

- 274 buildings in New London
  - 2,905,338 SQ FT
- 687 Acres
- 7,800 military personnel; 650 reservists drill there annually. The base employs 1,400 civilians and over1,000 contractors
- Active Naval Base
- Estimated 2,521 kW electrical requirement
- Estimated 8,001,420 BTU/hr thermal requirement (23.4 cubic feet natural gas/SQ FT)

* - Preliminary Assessment in Progress

Military Sites Analyzed* in CT

Air National Guard
Communication Station

- 4 buildings located in Orange
  - 60,673 SQFT
- 29 acres
- 214 personnel
  - 49 full-time
  - 165 traditional guard members
- Provide equipment personal during emergency
- The Control and Reporting Center (CRC) is responsible for providing:
  - Critical ground Command Control (C2)
  - Theater Air Defense (TAD)
  - Air Tasking Order (ATO)
- Estimated 50 kW electrical requirement (7.6 kWh/SQFT)
- Estimated 165,000 BTU/hr thermal requirement (23.4 cubic feet natural gas/SQFT)

* - Preliminary Assessment Completed

Potential Site Selection: Bradley International Airport

Selection Criteria[1]

Criteria		Notes
Hydrogen Demand	**Potential** **Potential**	Combined Fuel Cycle Transportation Fuel
Electricity Demand	✓	Transportation Center
Thermal Use	✓	Heating and Cooling
Military Application	✓	Air National Guard/Armory
Transportation Opportunities	✓	Forklift Truck / Transport Fleet / Service Vehicles
Energy Reliability	✓	Critical Facilities
Economic Development	✓	Hub for Domestic and International Travel
Environment: Ozone PM 2.5	 ✓ **0**	Non-Attainment area Attainment area
Educational Value / Community Support	✓	High Public Exposure
Energy Availability	✓	Served by Natural Gas

[1] Electrochemical Hydrogen Separator: Deployment Strategy 7/24/07 pg. #37

Technology: Electrochemical Hydrogen Separator (EHS)

- Efficient electricity and heat with hydrogen production
- 250 kW of electricity
- 300,000 BTU/hour of thermal energy
- 250 lbs/day of hydrogen[2]
- Overall system efficiency from 75 – 85%
- Expandable modular system

[2] Sufficient energy to power a heavy duty transit bus for approximately 700 miles

Financial Analysis

Summary Information

Capital and Installed Cost:	Dollars	$/KW
Fuel Cell System	SX	$X/KW
Fuel Cell Installation	SX	$X/KW
Contingency @ 10%	SX	$X/KW
H2 Extraction Turnkey	SX	$X/KW
Sales Taxes @6.0%	SX	$X/KW
Total Installed Cost	**$X**	**$X/KW**

Funding Sources:	Dollars	$/KW
CCEF	SX	$X/KW
Project Cash Flow	SX	$X/KW
Additional EHS Funding	SX	$X/KW
Other Funding	SX	$X/KW
Pre ITC Project Cost	**$X**	**$X/KW**
Federal ITC Credits	**$X**	**$X/KW**
Net Project Capital Cost	**$X**	**$X/KW**

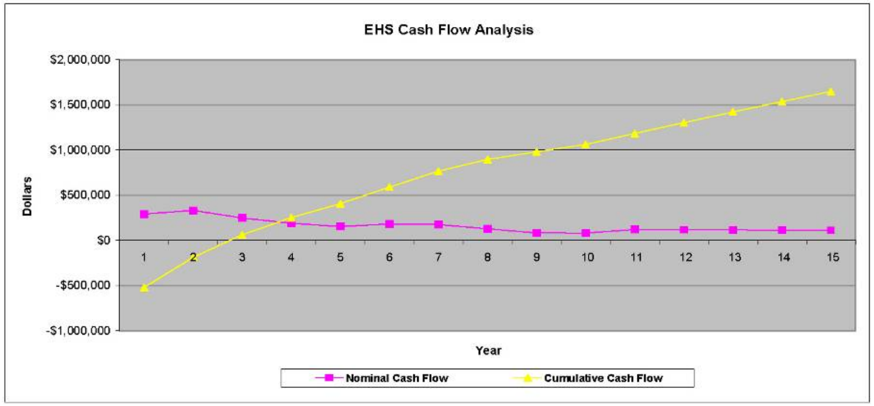
Fuel and Electricity cost:	
Nat. Gas Cost ($/mmbtu)	$12.10
Utility electricity cost (¢/kWh)	13.78
H2 Capacity Factor	80%
Boiler cost of heat ($/mmbtu)	$13.75

Financial Assumptions:	Rates:
Debt 0 %	7.00%
Equity 100 %	12.00%
Weighted Cost of capital	12.00%
Discount rate	12.00%
Years in the Analysis	15 Years
Finance term	12 Years
Depreciation (Fuel Cell)	5 Years
Depreciation (EHS)	7 Years
Depreciation (Re-stack)	5 Years

Technology	Fuel Cell
Manufactured by	FCE/EHS
Rated Output	300 KW

Cumulative NPV Revenues:	
Energy	$2,256,747
Hydrogen	$1,044,433
Thermal	$172,331
REC's	$397,519
Total Cumulative NPV Revenues	$3,871,031

Result of Analysis:	
Total NPV Project Cash Flow	**$1,331,683**
Net NPV Project Cost	**$812,200**
Project Net NPV Benefit	**$519,483**
Internal Rate of Return (IRR)	**27.4%**
Payback Period	**3 Years**



Prepared by Connecticut Center for Advanced Technology

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Energy Value: Hydrogen vs. Diesel Buses

Hydrogen Fuel Cell Bus

- Energy Efficiency
  - 12.4 mpge
  - 52.4 ge/day
- Zero Carbon Emissions

Diesel Transit Bus

- Energy Efficiency
  - 3.86 mpge
  - 168.4 ge/day
- Carbon Emissions
  - Over 3,200 lbs/day

Environmental Value: Transportation Emission Reductions

Potential Annual Emission Reductions per Vehicle Using Hydrogen Fuel Cell Propulsion Systems (pounds/year)			
	Possible Emission Reductions per year from Replacement of a Gasoline Fueled Passenger Car	Possible Emission Reductions per year from Replacement of a Gasoline Fueled Light Truck	Possible Emission Reductions per year from Replacement of a Conventional Diesel Transit Bus
NO_X	26.2	37.7	1,019.9
SO_2	0.192	0.299	1.746
CO_2	10,169	15,772	182,984

- Ten transit buses would reduce NO_x emissions by 10,199 lbs per year, SO_2 by 17.46 lbs per year, and CO_2 by 1,829,840 lbs per year.
- Fuel cells would increase transportation efficiency by two to three times.

- Based upon hydrogen generated from renewable sources.

Environmental Value: Stationary Emission Reductions

Potential Average Annual Emissions Reduction and Energy Savings Associated with the Displacement of 40 MW of Conventional Fossil Fuel Generation			
Air Emissions		Energy Savings	
NO_X	224 tons	Btu	1.4 – 1.6 Trillion
SO_2	187 tons	No. 2 Oil Equivalent	10 - 12 Million Gallons
CO_2	144,365 tons		

- Displacement of 40 MW of conventional fossil fuel with fuel cells for 10 years would reduce NO_x emissions by 2,240 tons, SO_2 by 1,870 tons and CO_2 by 1,443,650 tons.

Potential Partnerships

- Federal
  - U.S. Department of Defense
  - U.S. Department of Energy
  - U. S. Department of Transportation
  - Federal Aviation Administration
  - U.S. Department of Homeland Security
  - Clean Cities Coalitions
- State
  - Connecticut Clean Energy Fund
  - Department of Public Utility Control
  - Department of Transportation and CTTransit
  - CT Department of Environmental Protection
- Private
  - Industry
  - Utilities

Summary

- Fuel Cell and hydrogen technology is now in use.
- There are favorable applications for a technology that can provide electricity, thermal energy, and hydrogen.
- Deployment of fuel cell and hydrogen applications is increasing.
- Deployment of vehicles must be coordinated with development of refueling stations.
- Public and private partnerships are needed to reduce risk and manage costs.
- Public investment is appropriate and justified.

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